

Title: Hybrid Anteroposterior–Posteroanterior Headless Screw Fixation Improves Biomechanical Stability of Capitellar Coronal Shear Fractures: A Paired Cadaveric Study

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Additional Declarations: No competing interests reported.

Abstract

OBJECTIVE:

To compare the biomechanical performance of a hybrid headless-screw construct (one anteroposterior [AP] and one posteroanterior [PA]) with a traditional PA-only (two PA screws) construct in a paired cadaveric model of capitellar coronal-shear fractures.

Methods:

Seven pairs of fresh-frozen cadaveric humeri were used. Simulated Bryan–Morrey type I coronal-shear capitellar fractures were created and fixed with Acutrak cannulated headless compression screws. Each pair received either hybrid fixation (one AP and one PA screw) or two PA screws. Constructs underwent cyclic loading followed by load-to-failure testing. Force and displacement were sampled at 100 Hz during selected cycles (cycles 1–10, 100–110 and 491–500). Data were analyzed using paired statistical tests; a p -value < 0.05 was considered significant.

Results:

Hybrid fixation showed greater initial stiffness than PA-only (277.8 ± 64.6 vs 166.6 ± 51.0 N/mm; $p = 0.036$). Although stiffness remained higher with hybrid after further cycling, later differences were not statistically significant. Load-to-failure was higher with hybrid (253.7 ± 75.8 vs 151.6 ± 29.9 N; $p = 0.014$). Failure displacement did not differ (1.21 ± 0.43 vs 1.06 ± 0.35 mm; $p = 0.42$). Overall, hybrid constructs demonstrated $\approx 67\%$ greater initial stiffness and $\approx 67\%$ greater failure load versus PA-only.

Conclusion:

In this paired cadaveric model of capitellar shear fractures, a hybrid AP–PA screw orientation improved early construct stiffness and increased failure tolerance compared with two PA screws. These biomechanical advantages may support early supervised motion while maintaining construct integrity, however, clinical correlation is required.

LEVEL OF EVIDENCE: IV (cadaveric biomechanical study).

Introduction

Capitellar fractures of the distal humerus are difficult to manage owing to their intra-articular nature and propensity to impair elbow function. Without appropriate treatment, sequelae include a restricted range of motion, persistent pain, and post-traumatic arthritis. Surgical options include open reduction and internal fixation (ORIF), arthroscopic techniques, and—selectively—fragment excision. Among these, ORIF is most commonly used because it permits anatomic reduction and stable fixation.

Coronal shear fractures typically result from axial and valgus loading, such as a fall on an outstretched hand. Headless compression screws are widely used for fixation; however, the optimal screw direction

remains debated [1–8] . Biomechanical data have suggested that PA screws may provide greater construct stability than AP screws, and small clinical series have reported favorable results with two PA screws. Nevertheless, AP screw placement can offer technical advantages, including easier access and less posterior soft-tissue dissection in minimally invasive approaches.

To date, the biomechanics of a hybrid configuration (one AP and one PA screw) have not been evaluated in a paired model. Therefore, the present study compared hybrid AP–PA fixation with PA-only fixation in a paired cadaveric model of capitellar fractures. We hypothesized that hybrid fixation would demonstrate greater or at least non-inferior mechanical stability compared with two PA screws.

Materials and Methods

Design and setting

A paired cadaveric biomechanical study was performed in a university biomechanics laboratory

Specimens and allocation.

Seven matched pairs of fresh-frozen cadaveric humeri (6 male, 1 female; mean age 60.4 years, range 51–65 years) were used. Within each pair, one side was randomized to hybrid fixation (one AP and one PA headless compression screw) and the contralateral side to PA-only fixation (two PA screws). Screening radiographs excluded gross osseous defects or previous surgical intervention. All soft tissues and musculature were removed from the humeri prior to testing.

Fracture model and reduction:

A standardized Bryan Morrey type I [9] coronal-shear osteotomy was created with a micro-saw using two osteotomies: (1) a coronal osteotomy at the posterior margin of the articular surface, and (2) a sagittal osteotomy along the lateral trochlear edge (Fig. 3). Fragments were anatomically reduced and held with a C-clamp before fixation. Guide Kirschner wires (K-wires, 1.6 mm) were used (Fig.4). Pilot drilling and screw insertion followed the manufacturer's recommendations for 4.0-mm headless compression screws (Acutrak® 2 Standard; Acumed, Hillsboro, OR, USA) (Fig.5). All osteotomies and screw fixations were performed by a single fellowship-trained shoulder-and-elbow surgeon to minimize inter-operator variability.

Fixation techniques

- Hybrid (AP–PA): K-wires were placed anterolaterally on the capitellum and posteromedially on the fragment to guide screw paths. Both screws were inserted perpendicular to the osteotomy plane. The AP screw was inserted first to achieve AP compression, followed by PA fixation.
- PA-only: Medial and lateral K-wires were placed at the same level, perpendicular to the osteotomy plane, and two identical screws were inserted. Final screw lengths were measured with a depth

gauge and recorded: AP screws mean 22 ± 3 mm (range 18–26 mm), PA screws: mean 24 ± 3 mm (range 20–28 mm). All screw heads were buried below the articular surface.

Biomechanical testing.

Mechanical testing was performed on a servo-hydraulic system (Landmark 370, MTS Systems, Eden Prairie, MN, USA). An investigator not involved in fixation performed testing. To apply loading, a proximal segment of a composite radius (Sawbones, Pacific Research Laboratories, Vashon, WA, USA) was secured to the actuator and articulated with the capitellum to simulate 20° of elbow flexion, the position associated with peak radiocapitellar contact forces [10] (Fig. 1). Constructs were cyclically loaded between 0–75 N at 1 Hz for 500 cycles. Force and displacement were sampled at 100 Hz during cycles 1–10, 100–110, and 491–500. Monotonic load-to-failure testing was then performed at a displacement rate of 0.5 mm/s. Failure was defined as a sudden drop in load during testing.

Outcomes and statistical analysis

Primary outcome variables were failure load and construct stiffness, evaluated at the beginning and end of cyclic loading. Data normality was assessed with the Shapiro–Wilk test. Paired comparisons were performed using a two-tailed paired Student's t-test for normally distributed data for normally distributed data or the Wilcoxon signed-rank test for non-normally distributed data). A p -value of <0.05 was considered statistically significant.

Results

Stiffness during cyclic loading.

Stiffness increased in both constructs across cycles (Fig. 2). At cycles 1–10, hybrid fixation demonstrated greater stiffness than PA-only (277.8 ± 64.6 vs 166.6 ± 51.0 N/mm; paired $\Delta = 111.2$ N/mm; $p = 0.036$), representing a 67% increase. although stiffness remained greater for hybrid at cycles 100–110 and 491–500 (289.3 ± 61.8 vs 194.6 ± 58.2 N/mm and 337.1 ± 95.6 vs 229.2 ± 45.3 N/mm, respectively), these later differences did not reach statistical significance.

Load to failure and failure displacement.

Hybrid constructs withstood a higher failure load than PA-only constructs (253.7 ± 75.8 vs 151.6 ± 29.9 N; paired $\Delta = 102.1$ N; $p = 0.014$), a 67% increase. Failure displacement did not differ significantly between groups (1.21 ± 0.43 vs 1.06 ± 0.35 mm; $p = 0.42$).

Discussion

Capitellar fractures are challenging to manage because of their complex intra-articular geometry, limited bone stock for purchase, and risk of complications. Headless compression screws are commonly used to resist shear and rotational displacement, yet the optimal screw orientation remains debated [11]. In

this paired cadaveric biomechanical study, a hybrid construct one AP and one PA screw demonstrated greater early construct stiffness and a higher load to failure than two PA screws in simulated coronal-shear fractures.

Drawbacks of two **AP** screws include traversal of the articular surface, which increases the risk of iatrogenic cartilage injury and may allow the fragment to collapse into the posterior cortex [12](Tarallo et al., 2021). In addition, access to the medial capitellum via an AP path is also limited by surrounding soft tissues, making precise placement demanding. Conversely, two **PA** screws fixation is constrained by a narrow posterior approach [2], and by the need to obtain secure purchase in fragments with scant subchondral bone while avoiding intra-articular penetration [3,12]. A **hybrid** configuration (one AP and one PA screw) facilitates effective compression across the fracture and offers more versatile trajectories.

The hybrid construct showed significantly greater initial stiffness ($p = 0.036$) and a higher failure load ($p = 0.014$), supporting the biomechanical premise that opposing compressive vectors improve stability. Combining anteroposterior (AP) and posteroanterior (PA) trajectories may better resist multidirectional shear at the radiocapitellar joint, particularly early after fixation. This added stability could enable earlier range-of-motion exercises to limit postoperative stiffness while maintaining construct integrity until union.

Prior biomechanical work suggested PA screws may confer greater stability than AP screws during cyclic loading, although some investigations reported trends without statistical significance [13]. In the present model, hybrid fixation sustained a **67% higher failure load** ($p = 0.014$) and exhibited **67% greater initial stiffness** ($p = 0.036$). With continued cycling, stiffness increased in both groups and the **relative** hybrid advantage narrowed, but a **~47%** stiffness benefit persisted by the end of testing.

These data suggest that a hybrid screw orientation confers greater **early mechanical stability**, which may limit interfragmentary micromotion and foster conditions favorable for osseous primary healing. The added stability could also permit **earlier, supervised elbow mobilization**—important because postoperative stiffness is a common complication after capitellar fracture fixation. Previous studies by Puloski et al. and Tarallo et al. have emphasized that immediate postoperative motion is essential in minimizing joint stiffness [12,14].

At the point of failure, the hybrid fixation configuration tolerated significantly higher loads compared to the PA-only fixation, highlighting its enhanced capacity to withstand physiologic stress and reducing the likelihood of construct failure under normal loading conditions. While headless compression screw fixation has generally demonstrated clinical success, previous studies have noted hardware failure as a potential drawback associated with these implants [3,13,15,16]. Our findings suggest that hybrid screw orientation offers improved resistance to catastrophic failure, which may translate into more durable fixation and reduced risk of hardware-related complications in clinical settings, particularly in active or load-bearing patients.

Limitations

This study has several limitations. First, all specimens came from older donors; although capitellar fractures are common in the elderly, these cadavers may not reflect the bone quality or healing potential of younger patients. Second, our testing used simplified loading that does not reproduce the elbow's complex, multidirectional forces during daily activities. Third, we modeled a Bryan–Morrey type I coronal-shear pattern, so the findings may not generalize to fractures with greater displacement, comminution, or trochlear extension. Finally, while hybrid fixation demonstrated superior early mechanics, we did not evaluate clinical endpoints (union, function, or complications), clinical studies are therefore necessary to confirm the relevance of these biomechanical results.

Conclusion

In this paired cadaveric model, hybrid AP–PA fixation demonstrated significantly greater early stiffness and higher failure load than two PA screws. These findings support a biomechanical advantage of opposing screw vectors for coronal capitellar fractures; further clinical studies are required to validate translation to patient outcomes.

Declarations

Ethics Approval and Consent to Participate:

Cadaveric specimens were obtained from de-identified donated bodies through institutional donation programs. Institutional review board approval was not required according to local regulations and institutional policy.

Consent to publish

Not applicable.

Availability of Data and Materials:

The datasets generated and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing Interests:

The authors declare that they have no competing interests.

Funding:

No external funding or grants were used for the completion of this study.

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Author Contributions:

Feras Qawasmi, MD: Conceptualization of the study, supervision of cadaveric experiments, manuscript drafting, and final approval of submitted version.

Sonia Slusarczyk, MSc: Biomechanical testing, data collection, and data analysis.

Steven I. Grindel, PhD: Statistical analysis, data interpretation, and critical manuscript review.

Hamza Murad, MD: Assistance in specimen preparation and fracture modeling.

Mei Wang, PhD: Data validation, review of biomechanical methods, and manuscript editing.

Mustafa Yassin, MD: Support in fixation procedures and methodological guidance

Level of Evidence: IV

Potential Conflicts of Interest and Funding Sources:

No outside funding or grants were used for the completion of this study. None are declared.

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We acknowledge Logan M. Andryk for help in the laboratory and Fadi Shweiki for creating the illustration.

Ethics approval and consent to participate

This study was conducted on human cadaveric specimens. According to national regulations and institutional policies, ethical approval and Institutional Review Board (IRB) review were not required, as the study did not involve living participants or identifiable human data. All cadaveric specimens were obtained through a legally authorized body donation program, with written informed consent provided prior to death for research and educational purposes. The study was conducted in accordance with the principles of the Declaration of Helsinki.

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Figures



Figure 1

Testing setup.

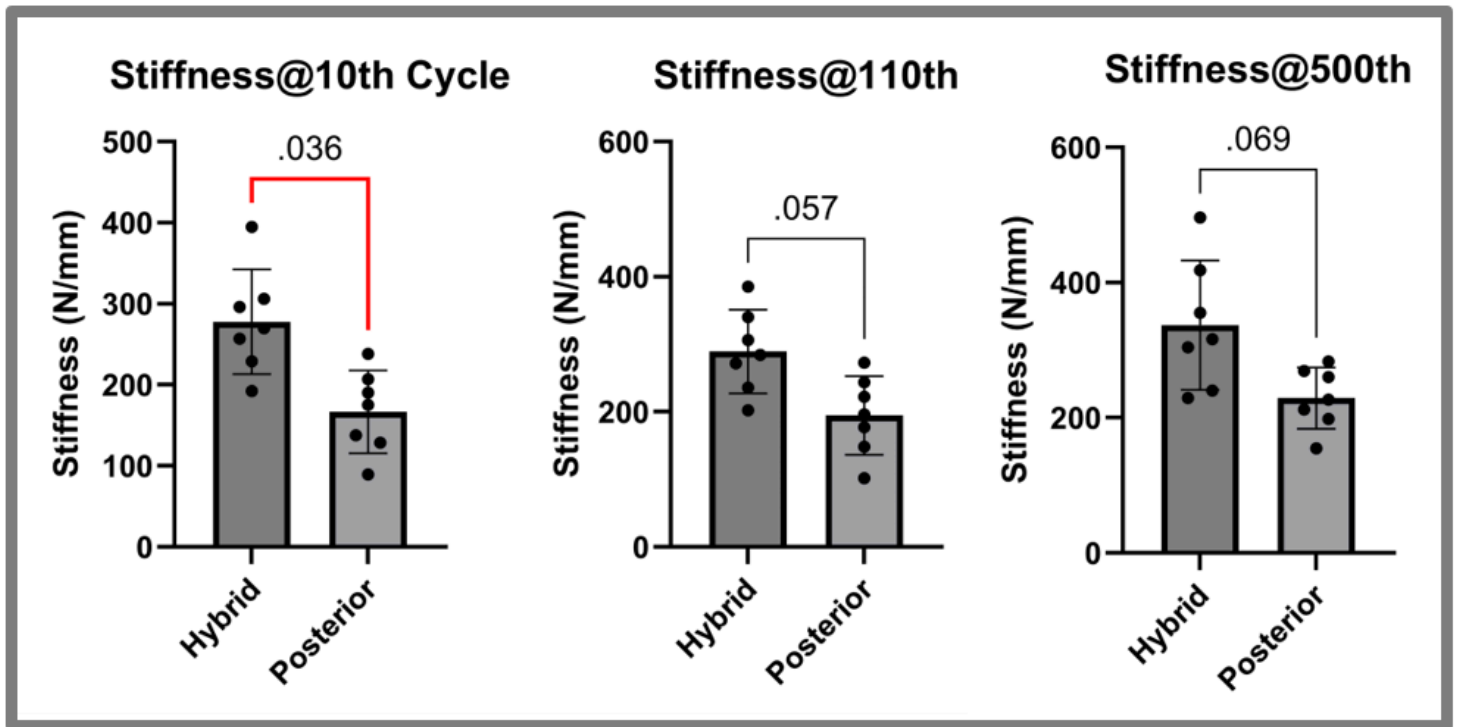


Figure 2

Construct stiffness at 10th, 110th, and 500th cycles.

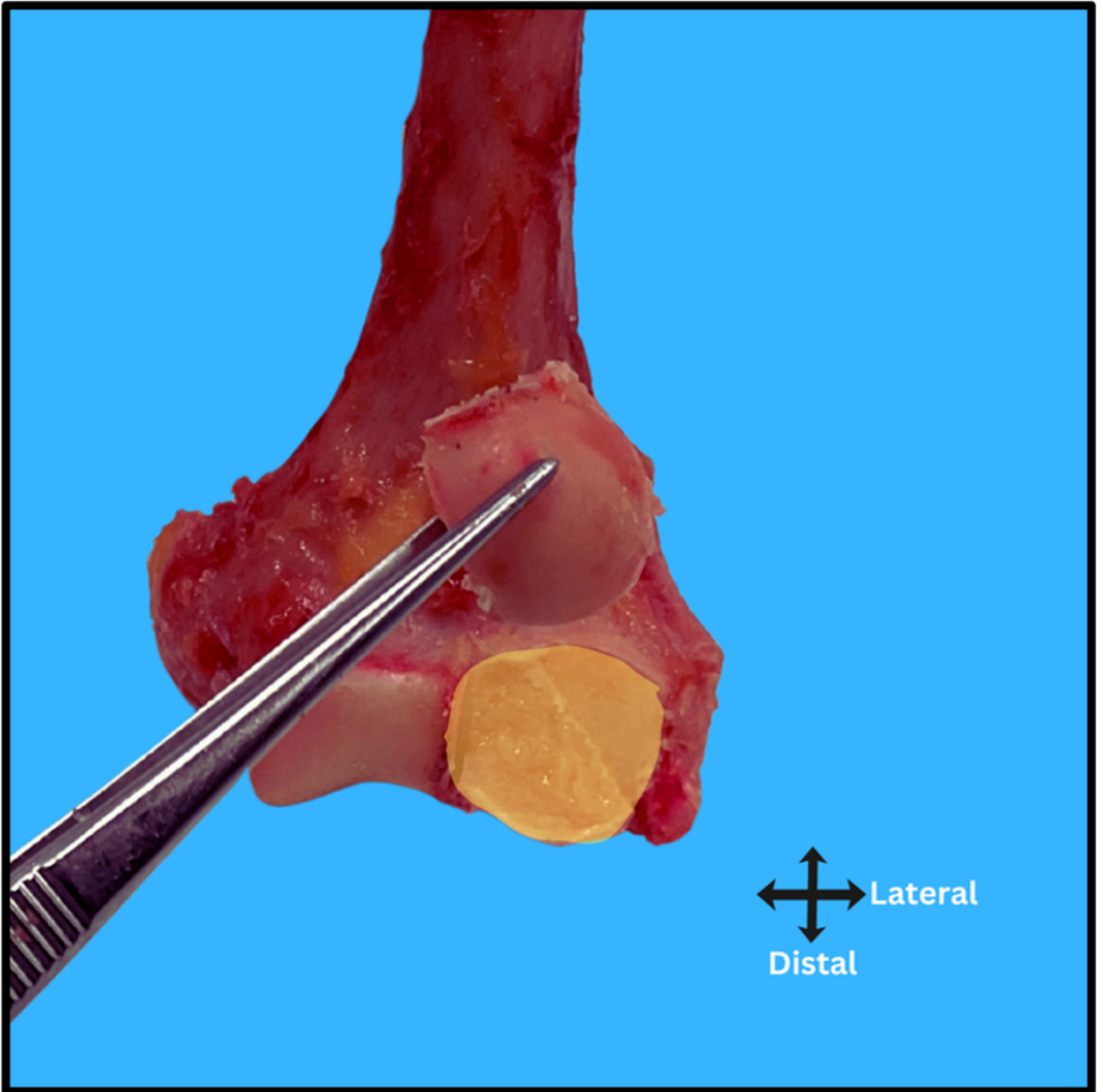


Figure 3

The osteotomy is held with a pickup; the yellow outline delineates the osteotomy bed.

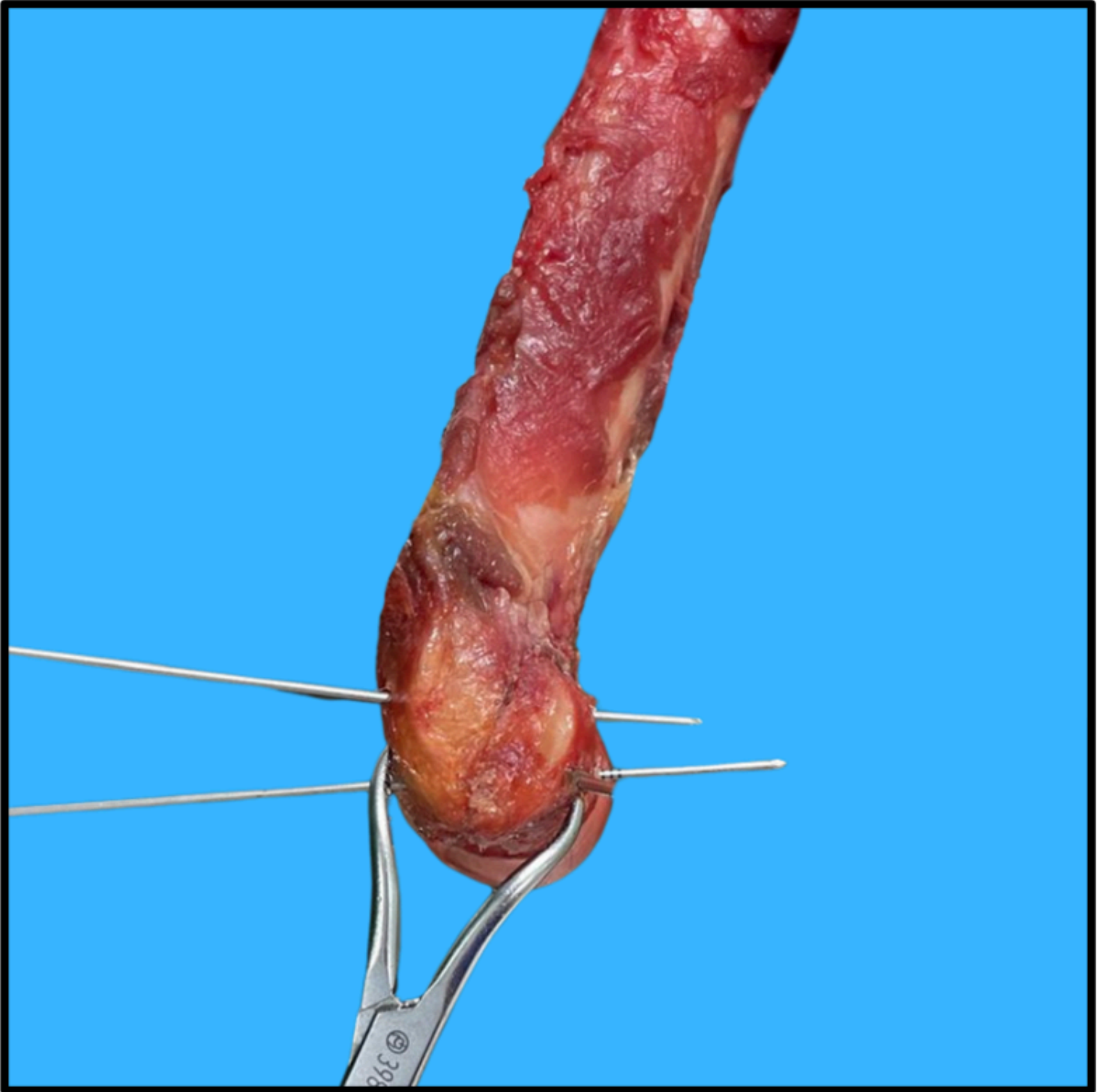


Figure 4

Reduction of the capitellar fracture with provisional K-wire fixation, just prior to drilling.

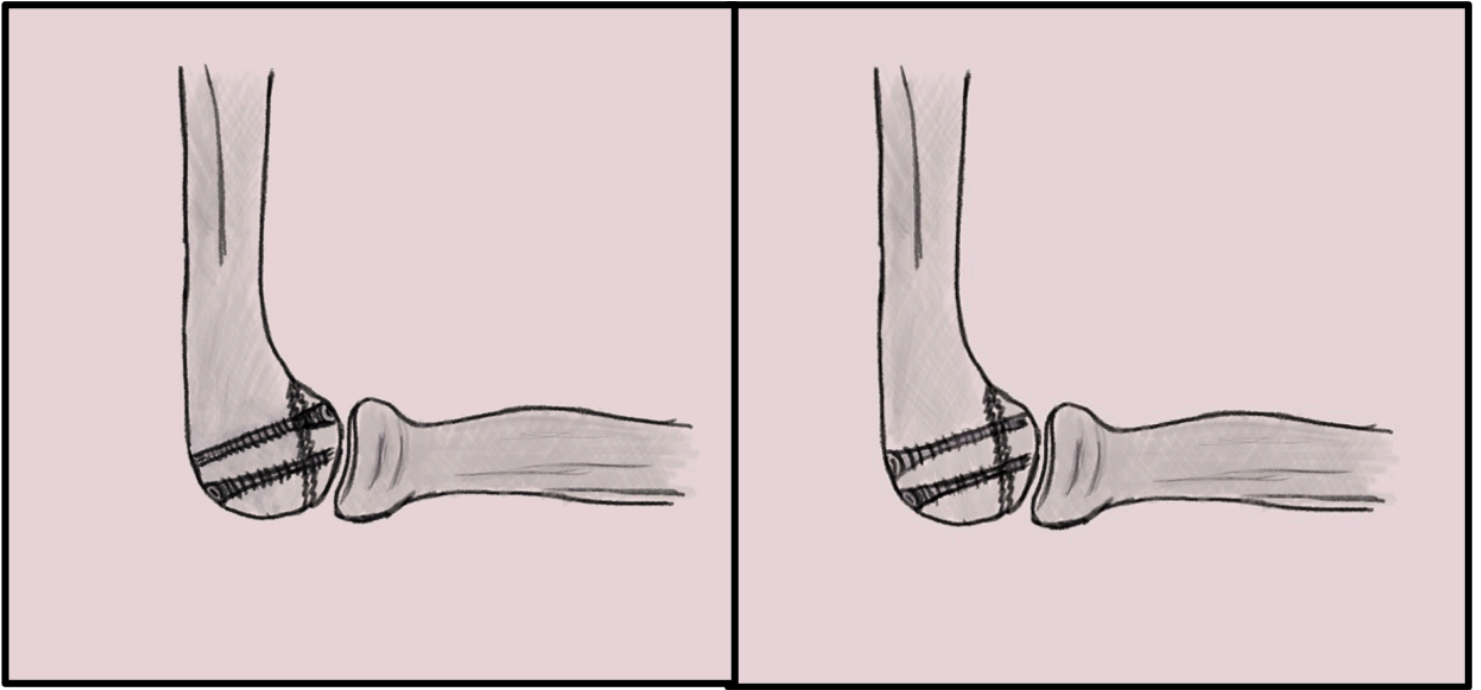


Figure 5

Hybrid AP/PA screw construct (left) versus two PA screws (right)